WHITE PAPER: Optical Monitoring System Improves Thin-Film Coating Accuracy

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THIN-FILM COATINGS: HISTORICAL CHALLENGES

There are many challenges to overcome to enable greater accuracy in optical thin-film coatings. In the past, coating design and manufacturing utilized a thin-film design software, such a TFCalc. The software would provide analysis, optical data, optimization, results, and coating files (see Fig. 1). The coating designer would develop the coating design using high-, medium-, and low-index materials to come up with a theoretical design. The coating design would be relatively easy; the difficulty would generally lie in replicating the design thickness and the material indices inside the coating chamber, without error.

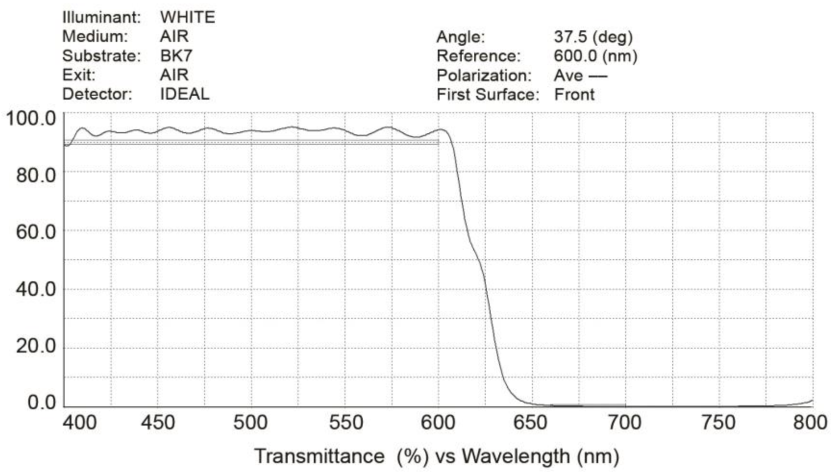

Figure 1 - TFCalc software graph shows optical design curve.

When the layer thickness is not accurate, all thin-film coatings are impacted. While true that the thickness variations affect all coatings, it is important to note that coatings with a slope, such as a long-wave pass (LWP) and/or short-wave pass (SWP), are often even more affected by any change in thickness. The change in thickness will cause the slope to move, which in turn, will cause the reflection and transmission values to change. This is why it is essential to have an effective process monitoring system in place.

Previously, there were two methods used in which to monitor the layers when coating them. One method was to use a crystal to monitor the physical thickness of each layer. Crystals, however, are very sensitive to temperature and pressure which is a problem because that makes them only accurate to around ±5%. Since many coatings might have as many as 50 layers, and if you have a window of error at ±5% you will end up with a coating that is no longer within your specifications.

The second method, and better choice, was to use a quarter-wave monitoring system with overshoots. Based on the layer thickness and work-to-monitor ratios, you could calculate how many quarter waves it would take to achieve the correct layer thickness. This technique yields better results than crystal monitoring; it is accurate to ±2%. However, a factor of ±2% can still be a serious issue, particularly when doing long runs.

Both of the methods discussed have a fundamental flaw: There is no sure way of knowing whether the index dispersion of the material remains the same as the original design during the actual evaporative process. If the material index is different, then the coating will not meet your specifications. It was this particular issue that became the catalyst for our coating company to seek out a better and more accurate solution.

INNOVATIONS IN THIN-FILM COATINGS

The real-time optical monitoring system implemented by Precision Glass & Optics (PG&O - www.pgo.com) can calculate the thickness of each layer to within 1 nm of the design thickness. It can also accurately show you what the index dispersion is *during* the coating process, so you know if and when there is a concern. The Eddy Company's SpectraLock system is an in-situ, full-spectrum optical monitoring and rate control system which has enabled our company to produce single- and multi-layered thin films with exceptional accuracy and ultra-precision that had previously been unattainable.

The variation of refractive index of a material as a function of wavelength is called index dispersion. The new monitoring system is based on this unique technology and is called **IDEM. or index dispersion enhanced monitoring**. It enables the production of optical coatings that precisely match the optical design *every time*, without error or iteration. It also allows the coating operator to precisely match the true index dispersion of each deposition material and the individual coating chamber characteristics, thus making it possible for the thin-film design to match the actual coating produced (see Fig. 2).

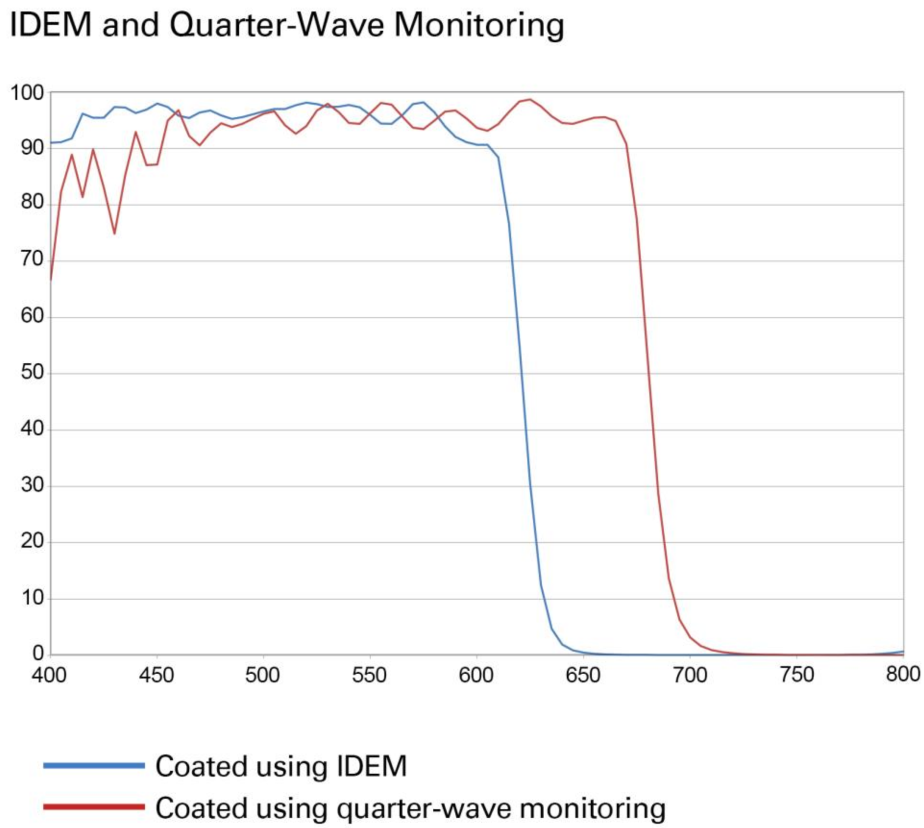

Figure 2 - The red line indicates optical monitoring with overshoots using quarter-wave monitoring; the blue line is the coating curve using the new IDEM monitoring system.

Preceding the IDEM innovation, thin-film design programs and optical coating systems have used standard materials reference table values for refractive index dispersion in the design and monitoring of the coatings. Unfortunately, the refractive index dispersion for each material in any given optical coating process deviates slightly from the standards.

As noted above, these small errors will multiply with each additional layer applied. Previously, in order to achieve successful results, it required expert compensation by highly trained coating specialists. With the new IDEM system in place, the coating thickness can be determined from zero up and the index dispersion can be seen from 1 nm. To reiterate, as each optical coating is layered, the IDEM method provides both rate control *and* process monitoring throughout each layer.

IDEM PROCESS:

The new index dispersion enhanced monitoring is an automated, full-spectrum optical system that provides calibration of the exact refractive index dispersion for each material substrate and process you use (see Fig. 3). Before fabrication of the designed coatings begins, a 2000 nm - 3000 nm calibration layer is deposited on witness chips and sample substrates for each coating process that is to be used. The refractive index dispersion of the coating on each witness chip is measured and the curves are stored for future use. Then the substrate samples are measured to determine the monitor-to-work ratio for each material.

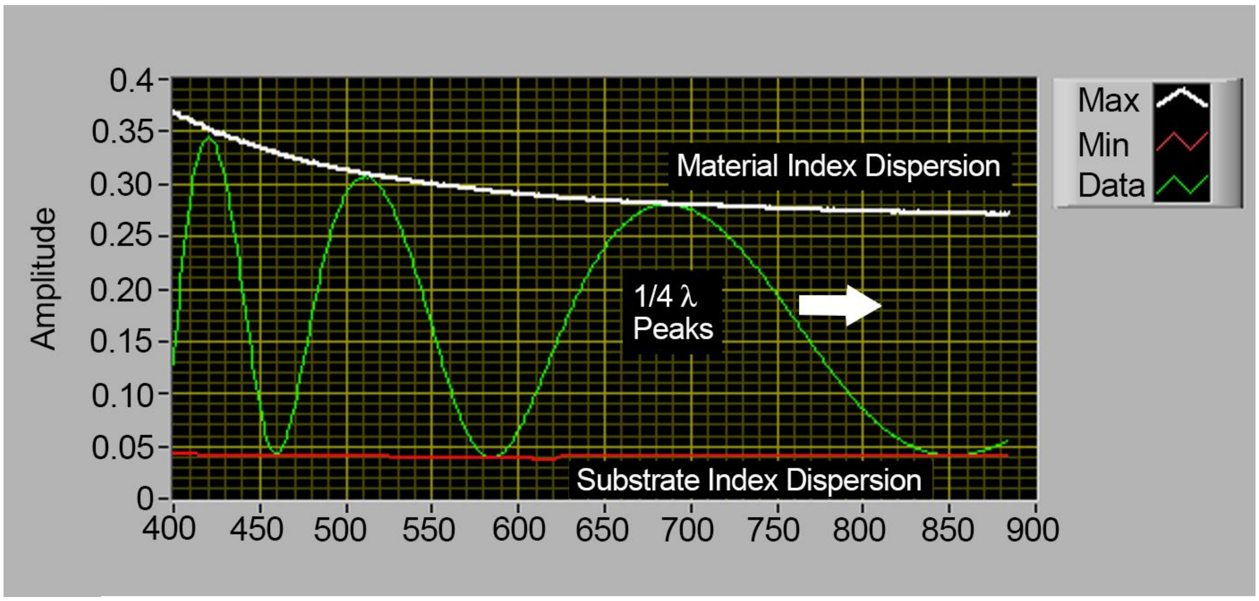

Figure 3 - SpectraLock display during calibration process. (Graph courtesy of Eddy Company).

These process index dispersions and monitor-to-work ratios are translated and loaded into both the thin film design software program and the SpectraLock controller for precise coating thickness control at each layer (see Fig. 4). This is the first commercially-available instrument that is capable of measuring in-situ the broadband optical index dispersion produced by the coating machine.

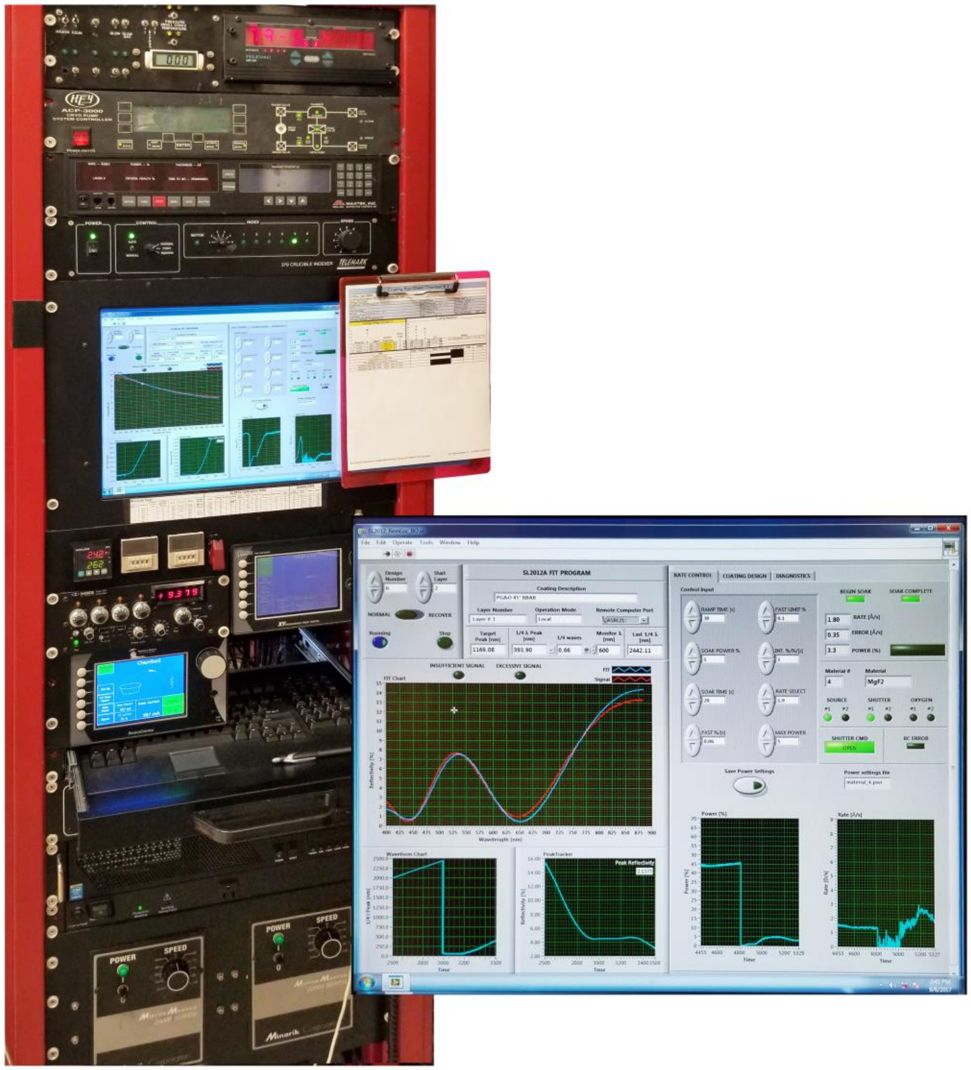

Figure 4 - SpectraLock Controller (left) and IDEM software screen capture (insert, right) during thin-film coating monitoring process.

CHALLENGES IN MULTIPLE COATING LAYERS:

The president of Eddy Company, Wayne Rodgers, explains, “When developing the IDEM system we were concerned about how many layers we could put on a chip with relative accuracy. So we put a 5-layer coating using 1-layer per chip, 2-layers per chip, 3-layers per chip, up to all 5 layers on one chip. We also ran two interrupted layer coatings. We interrupted it by removing the USB connection between the computer and the monitor…everything shut down. We reconnected and restarted the process. When we measured these, we got a little bit of a surprise. Prior to the full-spectrum monitoring, we've used single-wavelength monitoring and we've usually gotten within 1 percent from run to run. We assumed that this 1 percent was caused basically by the monitor-to-work ratio change. After these runs and we saw 0.19 percent or 0.2 percent deviation, we then realized the main cause of deviation was the monitoring technique and probably a 0.2 percent is somewhere in the monitor-to-work ratio problems."

He continues, "With this system of index dispersion and the correct monitor-to-work ratio, we can make a 37-layer design and just plain coat it; we measure, and it matches the design. There are no test runs necessary, there's no advantage to even doing a test run, because during the monitoring process we can see if the index dispersion of the material has changed from drift, or other factors."

SUMMARY:
Given the new capabilities made available by utilizing the IDEM system, the company now produces optical thin films that perfectly match the design programs and accurately predict the films that the coating chambers produce with optical thickness monitoring and control from 1 nm to over 5,000 nm (see Fig. 5). This process makes the new optical thin films approximately 10x more precise than ever before.

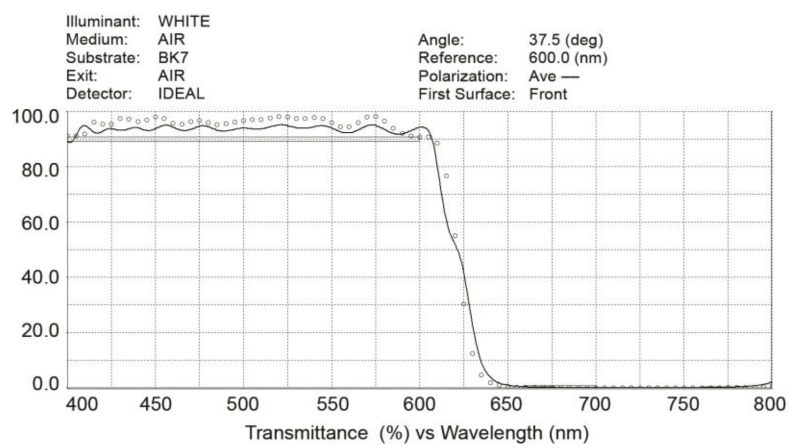

Figure 5 - The graph illustrates improved accuracy after the IDEM system was installed at PG&O. The original design curve is shown (black line), with the actual coating data imported, (represented by circles and superimposed over the design).

To learn more about the highly accurate results achieved with optical monitoring in thin-film coating processes, please call Precision Glass & Optics at +1 714-540-0126.